

# We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index  
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?  
Contact [book.department@intechopen.com](mailto:book.department@intechopen.com)

Numbers displayed above are based on latest data collected.  
For more information visit [www.intechopen.com](http://www.intechopen.com)



---

# A New Correlation for Prediction of Viscosities of Omani Fahud-Field Crude Oils

---

Nabeel Al-Rawahi, Gholamreza Vakili-Nezhaad,  
Ibrahim Ashour, Amin Fatemi

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/47813>

---

## 1. Introduction

Crude oil viscosity is an important physical property that controls and influences the flow of oil through porous media and pipes. The viscosity, in general, is defined as the internal resistance of the fluid to flow. Viscosity is an extremely important property from process and reservoir simulations to the basic design of a pipeline. Experimental liquid viscosities of pure hydrocarbons and their mixtures under pressure are important to simulating the behaviour of the fluid at reservoir conditions. Also, experimental measurements over a wide range of temperature and pressure are needed to test the effectiveness of semi-theoretical and empirical viscosity models [1]. Oil viscosity is a strong function of many thermodynamic and physical properties such as pressure, temperature, solution gas-oil ratio, bubble point pressure, gas gravity and oil gravity. Usually oil viscosity is determined by laboratory measurements at reservoir temperature. Viscosity is usually reported in standard PVT analyses. Oil viscosity correlations all belong to three categories: dead oil, saturated oil and undersaturated oil viscosity correlation. Numerous correlations have been proposed to calculate the oil viscosity. There have been a number of empirical correlations developed for medium and light crude oils [2]. However their applicability is limited to specific oils due to the complex formulation of the crude oils. These correlations are categorized into two types. The first type which refers to black oil type correlations predict viscosities from available field-measured variables including reservoir temperature, oil API gravity, solution gas- oil ratio, saturation pressure and pressure [3-7]. The second type which refers to compositional models is derived mostly from the principle of corresponding states and its extensions. In these correlations beside previous properties, other properties such as reservoir fluid composition, pour point temperature, molar mass, normal boiling point, critical temperature and acentric factor of components are used [8].

Ideally, viscosity is experimentally measured in laboratory. When such direct measurements are not available, correlations from the literature are often used. Fundamentally, there are two different types of correlations in the literature. The first group of correlations is developed using randomly selected datasets [9]. Such correlations could be called generic correlations. The second group of correlations, called specialized correlations, is developed using a certain geographical area or a certain class/type of oil. Correlations using randomly selected datasets may not be suitable for certain type of oils, or certain geographical areas. Even though the authors of the generic correlations want to cover a wide range of data, specialized correlations still work better for certain types of oils. Specialized correlations represent the properties of a certain type of oil or geographical area (for which they are developed) better than the general purpose correlations[9].

## 2. Experimental data and analysis

In this study, PVT experimental data of three sample oils from Omani dead oils have been measured. Each sample was introduced into Viscometer tube and inserted into the heating bath, set at initial temperature of 25°C with incremental temperature of 10 °C to a final temperature of 85 °C. The viscosity of each sample was measured using Automatic Rheometer System Gemini 150/200 3X Tbar with a temperature control accuracy of  $\pm 0.1$  C from Malvern company. The advantage of this instrument is particulate material tolerable, good repeatability, not so critical on misalignment and good temperature control accuracy of  $\pm 0.1$  C.

Before viscosity measurement of samples, the viscometer was calibrated frequently according to the instructions using standard calibration fluids provided by the supplier company and then was checked with pure liquids with known dynamic viscosity.

The viscometer was placed in a dry place and the viscosity measurement proceeded as soon as the sample was placed on viscometer cylinder. The sample is considered to be, no more in contact with the external environment, the viscometer was operated at single shear rate  $1 \text{ S}^{-1}$  using double gap (DG 24/27) at 298.15 K to 358.15 K. The double gap measuring system consists of a hollow cylinder with diameter 27.5 mm and height 53mm that is lowered into a cylindrical groove in the outer cylinder. The sample is contained in the double annular gap between them. Application material includes mobile liquids, suspensions and emulsion. The viscosity measurements were performed ten times and the results were reported as an average. Repeating the measurement several times could help attain data as close as possible to the true value in spite of the variations that might occur in the midst of an experimental process. The following table 1 shows the results of the measurements in the laboratory for the three samples.

Plotting the data yields fig.1 in which viscosity versus temperature has been drawn for the three samples. Fig.1 shows how viscosity changes according to temperature change and how scattered the data of this reservoir are.

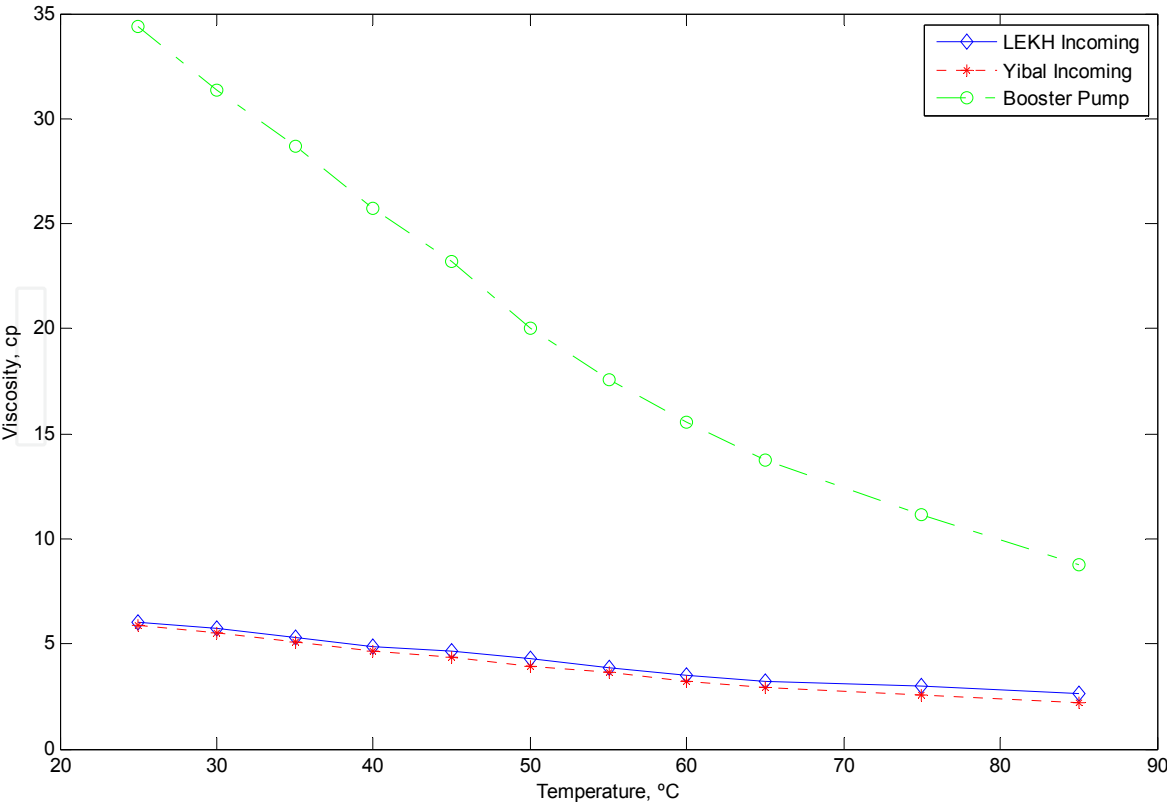
T (°C)	1. LEKH Incoming (cp)	2. Yibal Incoming(cp)	3. Booster Pump(cp)
25	6.0423	5.8935	34.3738
30	5.7104	5.5253	31.3382
35	5.3281	5.1092	28.6623
40	4.8819	4.6732	25.7045
45	4.6435	4.3483	23.2368
50	4.3218	3.9598	20.026
55	3.8478	3.6398	17.5592
60	3.4857	3.2408	15.55
65	3.1841	2.9537	13.7337
75	2.9678	2.5729	11.1786
85	2.6262	2.1869	8.7418

**Table 1.** Experimental data of three oil sample viscosities at different temperatures

Variable	Range
Oil gravity, °API	32.4 to 38.58
Pressure, atm	1
Temperature, °C	25 to 85

Number of dead oil observations = 3

**Table 2.** Description of data used from the samples



**Figure 1.** Experimental data of three oil sample viscosities at different temperatures

Some other properties of these oil samples (API degree and specific gravity) as reported by the laboratory are shown in table 3.

Sample Properties	1. LEKH Incoming	2. Yibal Incoming	3. Booster Pump
°API	38.58	39.34	32.4
Specific Gravity	0.832	0.8283	0.8633

**Table 3.** API gravity of the oil samples

**3. Development of the proposed correlations**

The most popular empirical models presently used in petroleum engineering calculations for predicting dead oil viscosity (gas-free crude or stock tank) are those developed by Beal [3], Beggs and Robinson [4], and Glasø [5]. Beal’s model [3] was developed from crude oil data from California, Beggs and Robinson’s model [4] was developed from the crude oils of an unknown location, whereas Galsø’s model [5] from crude oils in the North Sea. Recently, Labedi [6], and Kartoatmodjo and Schmidt [7] presented other empirical models for estimating dead crude oil viscosity for African crudes and using data bank respectively. All of these models have expressed dead oil viscosity as a function of both oil API gravity and reservoir temperature(*T*), see Appendix A. When these correlations were applied to data collected considerable errors and scatter were observed. These data, therefore, were used to develop new empirical correlations for dead or gas-free crude oil as a function of API gravity and temperature. Proposed correlation is based on real data, which covers Omani oil types, given in Table 1. Best results were obtained by multiple regression analysis from the following empirical model: The correlation for dead oil viscosity was developed by plotting  $\log_{10}(T)$  vs.  $\log_{10}\log_{10}(\mu_{DO} + 1)$  on Cartesian coordinates. It was found that each line represented oils of a particular API gravity. The equation developed is

$$\mu_{DO} = 10^X - 1 \tag{1}$$

where

$$X = y T^{-0.9863} \tag{2}$$

$$y = 10^Z \tag{3}$$

$$Z = 2.9924 - 0.11027\gamma_o \tag{4}$$

$\mu_{DO}$  is the dead oil viscosity in cp and *T* is the temperature in °C. Table 2 suggests the acceptable range of oil °API gravity between 32.4 to 38.58 and temperature between 25 to 85 °C. Development of these correlations neglects the dependence of oil viscosity on composition, since oils of widely varying compositions can have the same gravity. Viscosity does depend on composition, and if the composition is available other correlations [5-7]

exist that should be used for greater accuracy. However, the correlations presented here are easy to use and give fair accuracy and precision over an acceptable range of oil gravity and temperature. As is the case with any empirical study, extrapolation outside the range of the data used to develop the correlations should be done with caution [11,12].

## 4. Results and discussion

### 4.1. Validation of the proposed correlation

Table 4 shows the error percentage for all published dead crude oil models including the one proposed in this study for the Omani crudes. Table 4 reveals average relative error (ARE), absolute average relative error (AARE) and standard deviation (SD) for dead oil viscosity correlation respectively. ARE, AARE, and SD are defined as below.

$$ARE = \frac{1}{N} \sum_{i=1}^N \left( \frac{X_{experimental(i)} - X_{calculated(i)}}{X_{experimental(i)}} \right) \quad (5)$$

$$AARE = \frac{1}{N} \sum_{i=1}^N \left( \left| \frac{X_{experimental(i)} - X_{calculated(i)}}{X_{experimental(i)}} \right| \right) \quad (6)$$

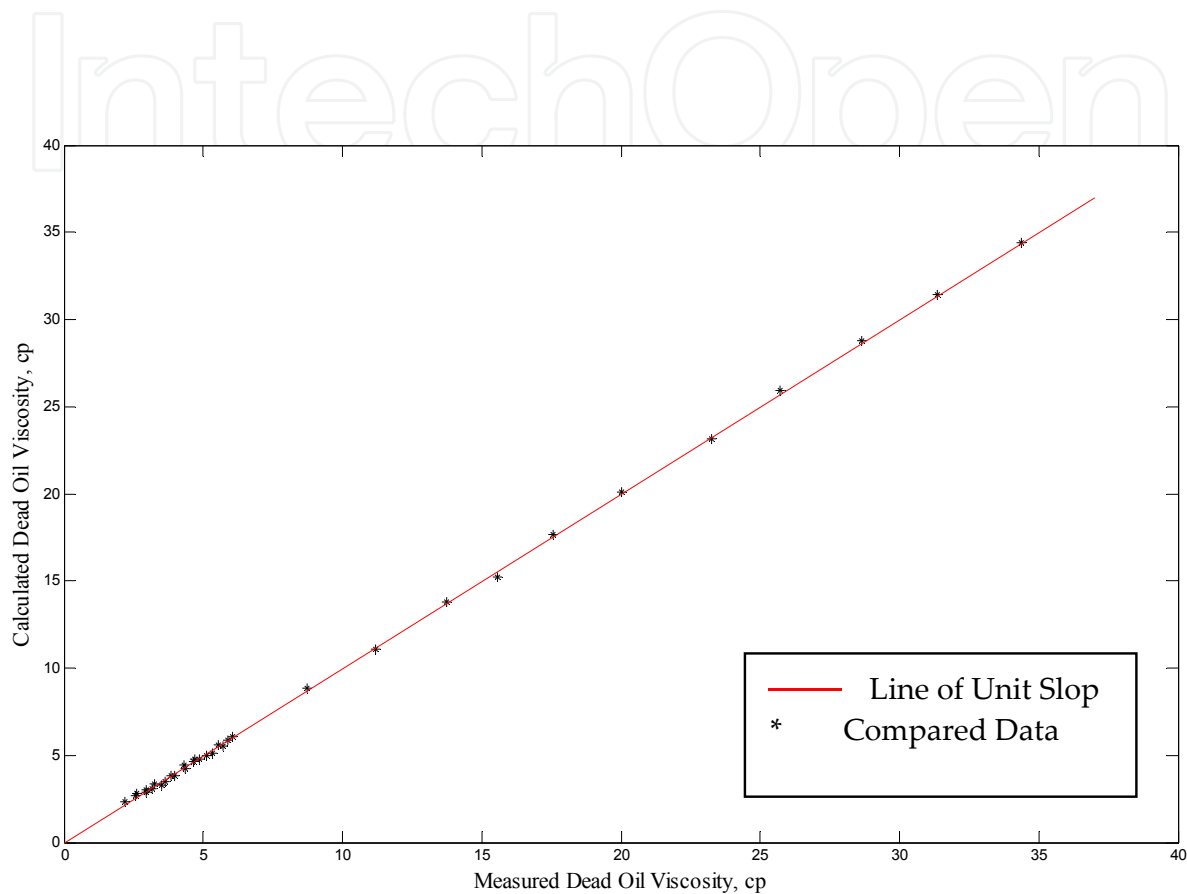
$$SD = \sqrt{\frac{1}{N-1} \sum_{i=1}^N \left( \left| \frac{X_{experimental(i)} - X_{calculated(i)}}{X_{experimental(i)}} \right| - AARE \right)^2} \quad (7)$$

Where  $i$  is the sample number and  $N$  is the total number of samples which is three. The validity of the dead oil model, Eq. (1), is checked in Table 4. The proposed model shows that dead crude oil viscosity decreases as the API gravity and/or the reservoir temperature increases. Table 4 compares the behaviour of the proposed model in this study to those in previously published models. It is important to note that in this table, errors reported by the authors for their models when predicting dead crude oil viscosities are also shown. The table depicts that Kartoatmodjo and Schmidt [7] model has an average absolute percentage error as high as 40% in predicting dead oil viscosity of the crudes. It is obvious from the figure that the new correlation provides results in good agreement with experimental values.

References	Average relative error %	Average absolute error %	Standard deviation %
Beal [3]	28.5	31.6	37.3
Beggs and Robinson [3]	7.5	21.2	28.0
Glaso [5]	24.9	27.4	31.9
Labedi [6]	-16.9	29.7	42.6
Kartoatmodjo and Shmidt [7]	30.9	33.1	37.25
Present Study	-2.5	19.2	25.8

**Table 4.** Accuracy of dead crude oil models for estimating viscosity of Omani Crude Oils

In the following figure accuracy of the proposed model against the Omani crude oil data has been examined. As depicted in fig. 2, laboratory measured dead oil viscosity data are plotted against calculated oil viscosity data and the points fall on the line of. This obviously shows that the measured quantities for the viscosity of the samples well match with the calculated quantities from the correlation presented in section 3.



**Figure 2.** Crossplot of  $\mu_{oD}$  versus calculated  $\mu_{oD}$ (this study)

## 5. Conclusions

In this study, using the laboratory data of Omani Fahud-field, a new empirical viscosity correlation has been developed. The proposed correlation covers an acceptable range of validity, and is superior to other published correlations in the literature. The comparisons with previously published correlations showcased in section 4 supports the fact that the proposed correlation better predicts the viscosity of this type of crude oils.

## Author details

Nabeel Al-Rawahi

*Department of Mechanical & Industrial Engineering,  
College of Engineering, Sultan Qaboos University, Muscat, Oman*

Gholamreza Vakili-Nezhaad\*, Ibrahim Ashour and Amin Fatemi

*Department of Petroleum and Chemical Engineering,  
College of Engineering, Sultan Qaboos University, Muscat, Oman*

Gholamreza Vakili-Nezhaad

*Department of Chemical Engineering, Faculty of Engineering,  
University of Kashan, Kashan, I. R. Iran*

Amin Fatemi

*Faculty of Civil Engineering and Geosciences, Geoscience & Engineering (G&E)  
Department, Petroleum Section, Delft University of Technology, CN Delft, The Netherlands*

## Acknowledgement

The research leading to these results has received funding from Petroleum Development Oman (PDO), Sultanate of Oman, through research agreement no. CTR #2009/111.

## Nomenclature

$T$  = temperature, °C

$\mu_{DO}$  = viscosity of gas-free/dead oil at  $T$ , cp

$^{\circ}API$  = oil gravity,  $^{\circ}API$

$ARE$  = average relative error

$AARE$  = absolute average relative error

$SD$  = standard deviation

## Appendix A. Dead oil viscosity models

A-1 Beal [1]

$$\mu_{od} = \left( 0.32 + \frac{1.8(10^7)}{API^{4.53}} \right) \left( \frac{360}{T - 260} \right)^a;$$

$$a = 10^{(0.43 + 8.33/API)}.$$

A-2 Beggs and Robinson [2]

$$\mu_{od} = 10^x - 1;$$

$$x = y(T - 460)^{-1.163},$$

$$y = 10^z,$$

A-3 Glasø [3]

$$\mu_{od} = [3.141(10^{10})](T - 460)^{-3.444}[\log(API)]^a;$$

$$a = 10.313[\log(T - 460)] - 36.447.$$

---

\* Corresponding Author



## A-4 Labedi [4]

$$\mu_{od} = \frac{10^{9.224}}{\text{API}^{4.7013} T_f^{0.6739}}.$$

## A-5 Kartoatmodjo and Schmidt [5]

$$\mu_{od} = 16(10^8) T_f^{-2.8177} (\log \text{API})^x;$$

$$x = 5.7526 \log(T_f) - 26.9718.$$

## 6. References

- [1] Salem S. Al-Marri, SPE, Kuwait Institute for Scientific Research, "Optimal Transformations for Multiple Regression: Application to Oil Viscosity Correlation Above and Below Bubble Point Pressures, SPE Saudi Arabia Section Technical Symposium, 9-11 May 2009, AlKhobar, Saudi Arabia
- [2] M.S. Hossain, SPE, C. Sarica, SPE, and H.-Q. Zhang, SPE, The U. of Tulsa, and L. Rhyne and K.L. Greenhill, SPE, Chevron, "Assessment and Development of Heavy Oil Viscosity Correlations ", 2005, SPE 97907-MS.
- [3] Beal, C. "Viscosity of Air, Water, Natural Gas, Crude Oil and Its Associated Gases at 011-Field Temperatures and Pressures," *Trans., AIME* (1946) 165, 94-115.
- [4] Chew, J. and Connally, C. A.: "A Viscosity Correlation for Gas- Saturated Crude Oils" *Trans., AIME* (1959) 216, 23-25.
- [5] Lohrenz, J., Bray, B. G., and Clark, C. R.: "Calculating Viscosities of Reservoir Fluids from their Compositions" *Journal of Petroleum Technology* (Oct. 1964) 1171-1176 *Trans., AIME*, 231.
- [6] Glasø O., "Generalized pressure-volume-temperature correlation for crude oil system" *Journal of Petroleum Technology* 1980;2:785-795.
- [7] Labedi R. "Improved correlations for predicting the viscosity of light crudes", *Journal of Petroleum Science Engineering* (1992);8:221-234.
- [8] Kartoatmodjo F, Schmidt Z. Large data bank improves crude physical property correlation. *Oil and Gas Journal* (1994);4:51-55.
- [9] Houppemt, A. H. and Lrelliez, M. B.: "Predicting the Viscosity of Hydrocarbon Liquid Phases From Their Composition," paper SPE 5057 presented at the SPE-AIME 49th Annual Fall Meeting, Houston, Oct. 6-9, 1974.
- [10] Little, J. E. and Kennedy, H. T.: "A Correlation of the Viscosity of Hydrocarbon Systems With Pressure, Temperature and Composition," *Sot. Pet. Eng. J.* (June 1968) 157-162; *Trans., AIME*, 243.
- [11] McCain, W.D., Jr.: "Reservoir-Fluid Property Correlations – State of the Art," SPE Reservoir Engineering (May 1991) 266-272.
- [12] Birol Dindoruk and Peter G. Christman, Shell Int. E & P. Inc., "PVT Properties and Viscosity Correlations for Gulf of Mexico Oils", SPE 71633